Chapter 5

Energy Efficient mmWave Beamspace MU-MIMO-NOMA Systems

5.1 Introduction

Beam selection algorithms have turned up as a solution for mmWave beamspace MU-MIMO communication system. They reduce RF complexity by selecting only desired beams [53, 109, 110, 113] because one RF chain is dedicated to one beam. These algorithms are deployed at the transmitter and they activate only those beams corresponding to which a user is present in the communication network. Rest of the beams remain inactive. Beam selection algorithms such as “MM” [109], “M-SINR” and “MC” [109], and “IA” beam selection [110] are in existence.

The simplest beam selection algorithm, “MM” selects beam according to channel realization of users and it may select the same beam for multiple users. The “M-SINR” and “MC” beam selection algorithms have high complexity. But, they select distinct beams for each user. Similarly, the “IA” beam selection algorithm selects distinct beam for each user with low complexity than the “M-SINR” and “MC” beam selection algorithm. The “QR-based” [53] and “MWM-based” [117] beam selection algorithms along with a new precoder was proposed in chapter 3, and it outperforms all the aforesaid beam selection algorithms. Further, the “distributed auction-based” decentralized beam selection algorithm, proposed in Chapter 4, performs as good as “MWM-based” beam selection algorithm [120].

Sometimes few users may demand the same beam in a mmWave small cell network. But, the beam selection algorithm will assign distinct beams to those users. Such users are also known as conflict users. In turn, their signals interfere with each other comparatively more than the other users present in the communication network. Such users degrade the system performance [121]. However, non-orthogonal

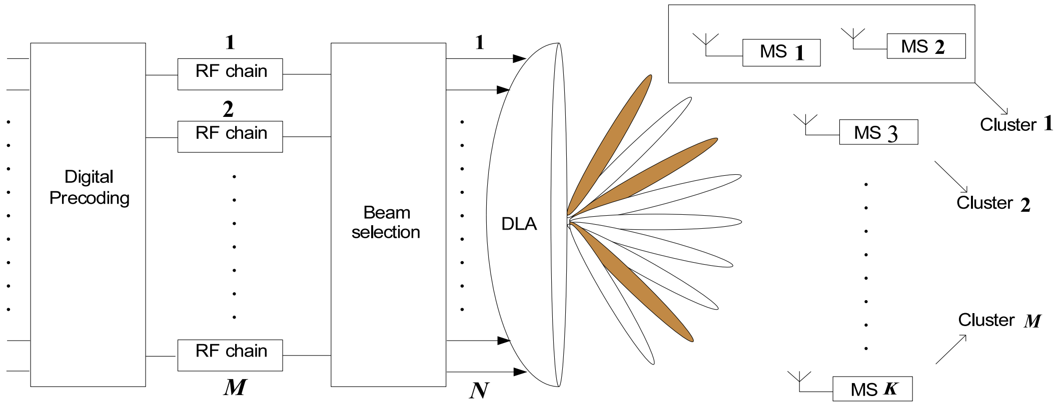

Figure 5.1 mmWave MU-MIMO-NOMA Communication System

multiple access (NOMA) principle in the power domain is capable of serving conflict users. In this method, symbols of conflict users are superimposed and transmitted over the same beam [121–123]. Thus, RF complexity get reduced further by deploying NOMA principle to the conflict users. But, a power allocation scheme is required for allocating power coefficients to the conflict users to perform successive interference cancellation (SIC) [121–123] since users are with the good channel condition will be assigned less power as compared to the users who are with the bad channel condition. It is worth noting that SIC is done at user's side to decode their intended symbol. A NOMA power allocation scheme to maximize the system capacity of massive MIMO-NOMA is proposed in [121] for the conflict users . Further, a NOMA power allocation scheme for mmWave communication employed with a single beam to assign power coefficients for each user is presented in [124, 125]. The paper [124] has realized the NOMA principle for the system having a transmitter employed with single beams and K users with single antenna, whereas the paper [125] realized the same with K users with multiple antennas. In this chapter, a power allocation scheme is proposed similar to [124, 125] for the conflict users for the beamspace system employed with N beams. Eventually, we propose a frame work for the beamspace system to select beams to users using the NOMA principle along with a NOMA power allocation scheme. The following work is detailed in this chapter.

1. There are some beam selection algorithms in the existence. But, no beam selection algorithm has selected beams using the NOMA principle. In this

chapter, a beam selection algorithm is proposed using the NOMA principle which selects the same beam for the conflict users. It means that a single RF chain can serve multiple users. By which we are saving the required number of RF chains.

2. Further, we propose a NOMA power allocation scheme for the conflict users which is aidful to perform SIC successfully at the users' side. Apart from SIC, the system performance is improved by employing a NOMA power allocation scheme at transmitter.

Thus, we investigate the mmWave beamspace MU-MIMO-NOMA Communication system to attain the excellent performance with less number of RF chains than the existing sytems.

5.2 mmWave Beamspace downlink MU-MIMO-NOMA Communication System Model

We are considering a downlink mmWave beamspace MU-MIMO-NOMA communication system, as shown in Fig. 5.1, having a transmitter equipped with N beams and K users equipped with a single receive antenna. Further, there are M clusters, and each cluster may contain one or more than one users. It is worth noting that, each cluster is served by a single beam. Thus, the input-output relation for a mmWave beamspace MU-MIMO-NOMA system [113] can be expressed as

$$\mathbf{y}_b = \mathbf{H}_b^H \mathbf{P}_b \mathbf{x} + \mathbf{w}_b, \tag{5.1}$$

where $\mathbf{H}_b^H = \mathbf{H}^H \mathbf{U} = [\mathbf{h}_{b,1}^H, \dots, \mathbf{h}_{b,K}^H]^H \in \mathbb{C}^{K \times N}$ is the beamspace channel matrix and $\mathbf{U}$ is beamforming matrix. Each $\mathbf{h}_{b,k}^H = \mathbf{h}_k^H \mathbf{U} = [h_{b,1k}^*, h_{b,2k}^*, \dots, h_{b,Nk}^*]^H \in \mathbb{C}^{N \times 1}$, $k = 1, \dots, K$. $\mathbf{H}^H$ is the spatial channel matrix, and $\mathbf{h}_k^H$ is the spatial channel vector for user k. $\mathbf{x} \in \mathbb{C}^{M \times 1}$ is the transmitted information vector and the vector element x_m, $m = \{1, 2, \dots, M\}$, is obtained by superimposing of the symbols of the corresponding users present in the cluster M. $\mathbf{y}_b \in \mathbb{C}^{K \times 1}$ is the received information vector, and $\mathbf{w}_b \in \mathbb{C}^{K \times K}$ denotes AWGN noise vector with $\mathbf{w}_b \sim \mathcal{CN}(0, N_0 \mathbf{I}_K)$. $\mathbf{P}_b \in \mathbb{C}^{N \times M}$ is, a digital precoder, to remove MUI while satisfying an average power constraint as

$$\mathbb{E}[\| \mathbf{P}_b \mathbf{x} \|^2] \leq \rho.$$

Further, the input-output relationship for a mmWave beamspace MU-MIMO-NOMA system, after beam selection, can be expressed as

$$\tilde{\mathbf{y}}_b = \tilde{\mathbf{H}}_b^H \tilde{\mathbf{P}}_b \mathbf{x} + \tilde{\mathbf{w}}_b, \tag{5.2}$$

where $\tilde{\mathbf{H}}_b^H = [\tilde{\mathbf{h}}_{b,1}^H, \ldots, \tilde{\mathbf{h}}_{b,K}^H]^H \in \mathbb{C}^{K \times M}$ is the beamspace channel matrix corresponding to the M selected beams and $\tilde{\mathbf{P}}_b \in \mathbb{C}^{M \times M}$ is a digital precoding matrix. $\tilde{\mathbf{w}}_b$ is the AWGN noise vector with $\tilde{\mathbf{w}}_b \sim \mathbb{C}\mathcal{N}(0, N_0 \mathbf{I}_K)$.

5.3 NOMA Principle

Various beam selection algorithms such as "MM" [113], "MC" [109], "IA" [110], "QR-based" [53], "MWM-based" [117], and "distributed acution-based" [120] are proposed to select the desired beam. Beam selection algorithm proposed in [53, 109, 117, 120] select distinct beams to each user. Users who desire the same beam but, they have been assigned a distinct beam, are known as conflict users. Such users cause interference to each other comparatively more than the other users present in the communication network. Hence, they degrade the system performance.

NOMA principle emerged as a solution to increase the spectral efficiency over orthogonal multiple access (OMA) principle for MU-MIMO system [121, 124, 125] which can also be pertinent for mmWave beamspace MU-MIMO system. The conflict users can also be served by the same beam using NOMA principle in the power domain. Here, the conflict users have been assigned power coefficients according to their channel condition in order to achieve high system performance [122]. In particular, symbols of the conflict users are superimposed and transmitted over the same beam. Further, SIC is applied at users' side to decode their intended symbols one by one through successive cancelling of undesired symbols until the desired symbol is obtained [121, 124, 125].

Users served with the same beam form a cluster. In the multi-user scenario, each cluster experiences inference from other clusters even though the cluster is having only a single user. Therefore, each cluster requires a dedicated precoding vector to eliminate multi-user interference. Let $\mathcal{M} = \{1, 2, \ldots, M\}$, $\mathcal{K} = \{1, 2, \ldots, K\}$ be the set of clusters and users, respectively. Further, each cluster is having $\mathcal{U}_m$ number of users, $m \in \mathcal{M}$, $0 < \mathcal{U}_m \leq k$, $k \in \mathcal{K}$. Each cluster contains exclusive users, $\mathcal{U}_i \cap \mathcal{U}_j = \emptyset$, $i \neq j$, $(i, j) \in \mathcal{M}$ and $\sum_{m}^{M} \mathcal{U}_m = K$. The beamspace channel vector after beam selection for a user l in the cluster m can be expressed as $\tilde{\mathbf{h}}_{b,m,l} \in \mathcal{C}^{M \times 1}$, $l = \{1, \ldots, \mathcal{U}_m\}$, and the corresponding precoding vector for the cluster m is $\tilde{\mathbf{p}}_{b,m}$. Therefore, the effective channel for a user l in the cluster m can be expressed as $\mid \tilde{\mathbf{h}}_{b,m,l}^{H} \tilde{\mathbf{p}}_{b,m} \mid$. Further, NOMA principle can be applied successfully, if the condition in (5.3) is satisfied by the cluster m

$$\mid \tilde{\mathbf{h}}_{b,m,1}^{H} \tilde{\mathbf{p}}_{b,m} \mid^2 \geq \mid \tilde{\mathbf{h}}_{b,m,2}^{H} \tilde{\mathbf{p}}_{b,m} \mid^2 \geq \ \ldots \ \geq \mid \tilde{\mathbf{h}}_{b,m,\mathcal{U}_m}^{H} \tilde{\mathbf{p}}_{b,m} \mid^2 . \tag{5.3}$$

Equation (5.3) justifies the condition in order to apply the NOMA principle to users of the cluster m. Note that, precoding vectors $\tilde{\mathbf{p}}_{b,m}$, $m \in \mathcal{M}$ are obtained by nullifying the inter-cluster interference. But, precoding vector of cluster m may not nullify inter-cluster interference to each user present in the cluster m [121]. Therefore, precoding vector $\tilde{\mathbf{p}}_{b,m}$ is obtained by nullifying the inter-cluster interference to the strongest user only because the strongest user has to receive its symbol by applying SIC [121]. It means other users, except the strongest user, in cluster m will receive the inter-cluster interference as well as intra-cluster interference. Finally, the net interference received by user l in the cluster m can be expressed as

$$I_{m,l} = \underbrace{\sum_{i=1, i \neq m}^{M} \sum_{j=1}^{\mathcal{U}_i} p_{i,j} \mid \tilde{\mathbf{h}}_{b,m,l}^{H} \tilde{\mathbf{p}}_{b,i} \mid^2}_{\text{inter-cluster interference}} + \underbrace{\sum_{j=1}^{l-1} p_{m,j} \mid \tilde{\mathbf{h}}_{b,m,l}^{H} \tilde{\mathbf{p}}_{b,m} \mid^2}_{\text{intra-cluster interference}} \tag{5.4}$$

where $p_{i,j}$ is the power supplied to user j in the cluster i which is decided through a power allocation scheme to appropriately decode the desired symbol through SIC.

The achievable performance for user l in the cluster m can be expressed as

$$R_{m,l} = \log_2 \left(\frac{p_{m,l} \mid \tilde{\mathbf{h}}_{b,m,l}^{H} \tilde{\mathbf{p}}_{b,m} \mid^2}{I_{m,l} + N_0} \right) \tag{5.5}$$

where N_0 is the noise power and the achievable performance for users in the cluster m is given as

$$R_m = \sum_{l=1}^{\mathcal{U}_m} R_{m,l}. \tag{5.6}$$

The net power supplied to K users is $\sum_{m=1}^{M} \sum_{l=1}^{\mathcal{U}_m} p_{i,j} = \rho$. In our work, we are supplying equal power to all the non-conflict users, i.e., $\frac{\rho}{K}$. However, the conflict users may not be assigned the same power, but they must satisfy a condition

$$\sum_{l=1}^{\mathcal{U}_m} p_{m,l} = \mathcal{U}_m \frac{\rho}{K}.$$

It means the net power supplied to each cluster is equal to $\mathcal{U}_m$ (number of users in the cluster m) times $\frac{\rho}{K}$. Thus, $p_{m,l}$ can be defined as

$$\begin{aligned} & p_{m,l} = \alpha_{m,l} \frac{\mathcal{U}_m\, \rho}{K}, \;\; l = \{1, \ldots, \mathcal{U}_m\}, \\ & \sum_{l=1}^{\mathcal{U}_m} \alpha_{m,l} \leq 1 \end{aligned} \tag{5.7}$$

where $\alpha_{m,l}$, $l = \{1, \ldots, \mathcal{U}_m\}$ are the power coefficients of users in the cluster m. Therefore, the net interference received at user l in the cluster m can be redefined as

$$I_{m,l} = \underbrace{\sum_{i=1, i \neq m}^{M} \frac{\mathcal{U}_i\, \rho}{K} \mid \tilde{\mathbf{h}}_{b,m,l}^{H} \tilde{\mathbf{p}}_{b,i} \mid^2}_{\text{inter-cluster interference}} + \underbrace{\sum_{j=1}^{l-1} \alpha_{m,j} \frac{\mathcal{U}_m\, \rho}{K} \mid \tilde{\mathbf{h}}_{b,m,l}^{H} \tilde{\mathbf{p}}_{b,m} \mid^2}_{\text{intra-cluster interference}}. \tag{5.8}$$

The power coefficients can be decided by applying a NOMA power allocation scheme. Then the net achievable performance of K users is given as, $R_s = \sum_{m=1}^{M} R_m$. Finally, “a beam selection algorithm accompanied by NOMA principle followed with a power allocation scheme” for this purpose and it is discussed in the next section.

Algorithm 6 Beam Selection Algorithm

Input: $\mathbf{H}_b, \mathcal{N} = \{1, 2, \ldots, N\}$

for $k = 1 \to K$ **do**

Find desired beam for user k:

$$n_k = \arg \max_{1<n\leq N} \{|h_{b,nk}|\}$$

Selecting beam as n_k:

$$\mathcal{B} = \mathcal{N} \cap \{n_k\}$$

Removing the selected beam form the set $\mathcal{N}$:

$$\mathcal{N} = \mathcal{N} \setminus \{n_k\}$$

end for

Selecting the beam which belongs to set $\mathcal{B}$:

$$\tilde{\mathbf{H}}_b = [\mathbf{H}_b]_{n\in\mathcal{B}}$$

5.3.1 Proposed Beam Selection Algorithm

The following beam selection algorithm has very low complexity, and it selects the same beam to the conflict users. We apply NOMA principle to conflict user and use Algorithm 6 to assign beam to a user. Hence the beamspace channel matrix can be expressed as

$$\tilde{\mathbf{H}}_b = [\mathbf{H}_b]_{n\in\mathcal{B}} \tag{5.9}$$

where $\tilde{\mathbf{H}}_b \in \mathbb{C}^{M\times K}$ is the beamspace channel matrix after beam selection. Next, we need to obtain a beamspace channel matrix having only the strongest users' channel vectors from each cluster as discussed in the previous sub-section. Then the beamspace channel matrix with the strongest users' channel vectors $\tilde{\mathbf{H}}_{b,s} \in \mathbb{C}^{M\times M}$ can be expressed as,

$$\tilde{\mathbf{H}}_{b,s} = [\tilde{\mathbf{h}}_{b,1,1}, \tilde{\mathbf{h}}_{b,2,1}, \ldots, \tilde{\mathbf{h}}_{b,M,1}] \tag{5.10}$$

where $\tilde{\mathbf{h}}_{b,m,1} \in \mathbb{C}^{M\times 1},\ \ m = \{1, \ldots, M\}$. Further, we need to evaluate precoding vectors to nullify inter-cluster interference. We apply ZF scheme [126] on $\tilde{\mathbf{H}}_{b,s}$ and the precoding vectors for each cluster are obtained. Hence, precoding matrix is obtained as

$$\tilde{\mathbf{P}}_b = \frac{(\tilde{\mathbf{H}}_{b,s}^H)^{-1}}{\|(\tilde{\mathbf{H}}_{b,s}^H)^{-1}\|_F} \in \mathbb{C}^{M\times M}, \tag{5.11}$$

where $\tilde{\mathbf{P}}_b = [\tilde{\mathbf{p}}_{b,1}, \tilde{\mathbf{p}}_{b,2}, \dots, \tilde{\mathbf{p}}_{b,M}]$, and $\tilde{\mathbf{p}}_{b,m} \in \mathbb{C}^{M\times 1}$, $m \in \{1,\dots,M\}$ and F stands for Frobenius norm.

5.3.2 **Proposed NOMA Power Allocation Scheme**

It is necessary to guarantee user fairness and decode received symbol corresponding to each user by applying SIC. We allocate power to the cluster m to maximize the minimum achievable rate (the max-min fairness) among the $\mathcal{U}_m$ number of users. Thus, power allocation optimization in the cluster m is defined as,

$$\begin{aligned} &\max_{\alpha_{m,1},\dots,\alpha_{m,\mathcal{U}_m}} \min_{p}\{R_{m,p}\} \\ &C1: \quad \text{subject to} \sum_{l=1}^{\mathcal{U}_m} \alpha_{m,l} \leq 1 \\ &C2: \quad \alpha_{m,p} \geq 0, l = \{1,\dots,\mathcal{U}_m\} \end{aligned} \tag{5.12}$$

where $\alpha_{m,l}$, $l = \{1,\dots,\mathcal{U}_m\}$ is the power coefficients. Constraint $C1$ satisfies the power constraint for the cluster M as discussed in (5.7). Constraint C2 ensures some amount of power to each user present in the cluster M.

It is difficult to solve the optimization problem in (5.12). So, we introduce a new variable to simplify the problem as suggested in [127]. Say $\mathcal{R}$ is the minimum achievable rate among the $\mathcal{U}_m$ number of users then optimization problem in (5.12) can be re-defined as

$$\begin{aligned} &\max_{\alpha_{m,1},\dots,\alpha_{m,\mathcal{U}_m},\mathcal{R}} \mathcal{R} \\ &C1: \quad \text{subject to} \sum_{l=1}^{\mathcal{U}_m} \alpha_{m,l} \leq 1 \\ &C2: \quad R_{m,l} \geq \mathcal{R}, l = \{1,\dots,\mathcal{U}_m\} \\ &C3: \quad \alpha_{m,l} \geq 0, l = \{1,\dots,\mathcal{U}_m\} \end{aligned} \tag{5.13}$$

where constraint $C2$, $R_{m,l} \geq \mathcal{R}, l = \{1,\dots,\mathcal{U}_m\}$, is a sufficient and necessary conditions for ensuring the minimum achievable rate by each user. Further, the achievable rate of each user should not be lower than $\mathcal{R}$ and there must be at least one user, whose achievable rate $R_{m,l}$ is equal to $\mathcal{R}$. Yet, we can always maximize $\mathcal{R}$ to minimize the gap between $R_{m,l}$ and $\mathcal{R}$. Due to the non-linearity of the equations, $R_{m,l} \geq \mathcal{R}, l = \{1, \ldots, \mathcal{U}_m\}$, this optimization problem is still difficult to solve. However, if we satisfy all the above constraints, we can obtain the solution.

In the next step, we find the power coefficients which satisfy the constraints, $C3 : \alpha_{m,l} \geq 0$, and $C2 : R_{m,l} \geq \mathcal{R}, p = \{1, \ldots, \mathcal{U}_m\}$, over variable $\alpha_{m,l}$, $l = \{1, \ldots, \mathcal{U}_m\}$. Thus, the optimization variables $\alpha_{m,l}$, $l = \{1, \ldots, \mathcal{U}_m\}$ are obtained as

$$
\begin{aligned}
\alpha_{m,1} &= \eta \left(\frac{KN_0}{\mathcal{U}_m \rho \mid \tilde{\mathbf{h}}_{b,m,1}^H \tilde{\mathbf{p}}_{b,m} \mid^2} \right), \\
\alpha_{m,2} &= \eta \left(\alpha_{m,1} + \frac{\sum_{i=1, i \neq m}^{M} \frac{\mathcal{U}_i \rho}{K} \mid \tilde{\mathbf{h}}_{b,m,2}^H \tilde{\mathbf{p}}_{b,i} \mid^2 + N_0}{\frac{\mathcal{U}_m \rho}{K} \mid \tilde{\mathbf{h}}_{m,2}^H \tilde{\mathbf{p}}_{b,m} \mid^2} \right), \\
&\vdots \\
&\vdots \\
\alpha_{m,\mathcal{U}_m} &= \eta \left(\sum_{l=1}^{\mathcal{U}_m - 1} \alpha_{m,l} + \frac{\sum_{i=1, i \neq m}^{M} \frac{\mathcal{U}_i \rho}{K} \mid \tilde{\mathbf{h}}_{b,m,\mathcal{U}_m}^H \tilde{\mathbf{p}}_{b,i} \mid^2 + N_0}{\frac{\mathcal{U}_m \rho}{K} \mid \tilde{\mathbf{h}}_{b,m,\mathcal{U}_m}^H \tilde{\mathbf{p}}_{b,m} \mid^2} \right),
\end{aligned}
\tag{5.14}
$$

where $\eta = 2^{\mathcal{R}} - 1$, and $\alpha_{m,l}$, $l = \{1, \ldots, \mathcal{U}_m\}$. The set of equations (5.14) are obtained by satisfying constraint $C2$, also satisfies constraint $C3$. Further, the above optimization problem can be re-defined as

$$
\begin{aligned}
&\max_{\eta} \{\eta\} \\
C1 : \quad &\text{subject to} \sum_{l=1}^{\mathcal{U}_m} \alpha_{m,p} \leq 1
\end{aligned}
\tag{5.15}
$$

using a set of equations given by (5.14) and we can write

$$
\begin{aligned}
\sum_{l=1}^{\mathcal{U}_m} \alpha_{m,l} = (1+\eta) \sum_{l=1}^{\mathcal{U}_m - 1} \alpha_{m,l} + \\
\eta \left(\frac{\sum_{i=1, i \neq m}^{M} \frac{\mathcal{U}_i \rho}{K} \mid \tilde{\mathbf{h}}_{b,m,\mathcal{U}_m}^H \tilde{\mathbf{p}}_{b,i} \mid^2 + N_0}{\frac{\mathcal{U}_m \rho}{K} \mid \tilde{\mathbf{h}}_{b,m,\mathcal{U}_m}^H \tilde{\mathbf{p}}_{b,m} \mid^2} \right).
\end{aligned}
\tag{5.16}
$$

Further, substituting the value of $\alpha_{m,\mathcal{U}_m-1}$ in (5.16) we obtain,

$$\sum_{l=1}^{\mathcal{U}_m} \alpha_{m,l} = (1+\eta) \sum_{l=1}^{\mathcal{U}_m-2} \alpha_{m,l} + (1+\eta)\alpha_{m,\mathcal{U}_m-1} + \eta \left(\frac{\sum_{i=1,i\neq m}^{M} \frac{\mathcal{U}_i \rho}{K} \mid \tilde{\mathbf{h}}_{b,m,\mathcal{U}_m}^H \tilde{\mathbf{p}}_{b,i} \mid^2 + N_0}{\frac{\mathcal{U}_m \rho}{K} \mid \tilde{\mathbf{h}}_{b,m,\mathcal{U}_m}^H \tilde{\mathbf{p}}_{b,m} \mid^2} \right), \tag{5.17}$$

$$\sum_{l=1}^{\mathcal{U}_m} \alpha_{m,l} = (1+\eta)\eta \sum_{l=1}^{\mathcal{U}_m-2} \alpha_{m,l} + (1+\eta)\eta \left(\frac{\sum_{i=1,i\neq m}^{M} \frac{\mathcal{U}_i \rho}{K} \mid \tilde{\mathbf{h}}_{b,m,\mathcal{U}_m-1}^H \tilde{\mathbf{p}}_{b,i} \mid^2 + N_0}{\frac{(\mathcal{U}_m-1)\rho}{K} \mid \tilde{\mathbf{h}}_{b,m,\mathcal{U}_m-1}^H \tilde{\mathbf{p}}_{b,m} \mid^2} \right) + \eta \left(\frac{\sum_{i=1,i\neq m}^{M} \frac{\mathcal{U}_i \rho}{K} \mid \tilde{\mathbf{h}}_{b,m,\mathcal{U}_m}^H \tilde{\mathbf{p}}_{b,i} \mid^2 + N_0}{\frac{\mathcal{U}_m \rho}{K} \mid \tilde{\mathbf{h}}_{b,m,\mathcal{U}_m}^H \tilde{\mathbf{p}}_{b,m} \mid^2} \right). \tag{5.18}$$

One can repeat this step for all the values of $\alpha_{m,l}$, $l = \mathcal{U}_m - 1, \mathcal{U}_m - 2, \ldots, 1$ and obtain

$$\sum_{l=1}^{\mathcal{U}_m} \alpha_{m,l} = \sum_{l=1}^{\mathcal{U}_m} (1+\eta)^{\mathcal{U}_m - l} \eta \left(\frac{\sum_{i=1,i\neq m}^{M} \frac{\mathcal{U}_i \rho}{K} \mid \tilde{\mathbf{h}}_{b,m,l}^H \tilde{\mathbf{p}}_{b,i} \mid^2 + N_0}{\frac{\mathcal{U}_m \rho}{K} \mid \tilde{\mathbf{h}}_{b,m,l}^H \tilde{\mathbf{p}}_{b,m} \mid^2} \right). \tag{5.19}$$

Now the optimization problem in (5.15) can be written as

$$\max_{\eta} \{\eta\}$$

$$C1: \quad \text{subject to} \sum_{l=1}^{\mathcal{U}_m} (1+\eta)^{\mathcal{U}_m - l} \eta \times \left(\frac{\sum_{i=1,i\neq m}^{M} \frac{\mathcal{U}_i \rho}{K} \mid \tilde{\mathbf{h}}_{b,m,p}^H \tilde{\mathbf{p}}_{b,i} \mid^2 + N_0}{\frac{\mathcal{U}_m \rho}{K} \mid \tilde{\mathbf{h}}_{b,m,l}^H \tilde{\mathbf{p}}_{b,m} \mid^2} \right) \leq 1. \tag{5.20}$$

Now we need to solve optimization problem (5.20) to obtain the closed-form expression of $\alpha_{m,l}$, $l = \{1, \ldots, \mathcal{U}_m\}$ and thus, the expression of $\alpha_{m,l}$, $l = \{1, \ldots, \mathcal{U}_m\}$ can be obtained by a set of equations, given by (5.14). Yet, the constraint of the optimization problem (5.20) is non-convex. So, it is computationally tough to directly find the solution. However, the optimization problem (5.20) is having only a single optimization variable, i.e., η. Therefore, we can find the value of η in the range of $[0, \tau]$ using the bisection method, where τ is the upper bound. The value of $\eta = 2^{\mathcal{R}} - 1$ represents the minimum SINR among the $\mathcal{U}_m$ number of users in the cluster m.

To find τ, we allocate all power, i.e., $\sum_{l=1}^{\mathcal{U}_m} p_{m,l} = \mathcal{U}_m \frac{\rho}{K}$, to user with the best channel condition, i.e., user 1 in the cluster m, then user 1 can achieve the highest SINR. Thus, the highest trasnmission rate for the strongest user in the cluster m is

Algorithm 7 Power allocation Algorithm for cluster m

Input: precoding vector: $\tilde{\mathbf{p}}_{b,m}$, channel vector: $m = \{1, \ldots, M\}$, $\tilde{\mathbf{h}}_{b,m,l}$, $l = \{1, \ldots, \mathcal{U}_m\}$,

Evaluate upper bound: τ =

$$\log_2 \left(\frac{\frac{\rho \mathcal{U}_m}{K} \mid \tilde{\mathbf{h}}_{b,m,1}^H \tilde{\mathbf{p}}_{b,m} \mid^2}{N_0} \right)$$

Define the maximum and minimum vale of η:

$$\eta_{min} = 0, \eta_{max} = \tau$$

Evaluate:

$$\eta = \frac{\eta_{min} + \eta_{max}}{2}$$

The search accuracy: δ

while $\eta_{max} - \eta_{min} < \delta$ **do**

  if $f(\eta) < 1$ **then**

    Set as a minimum vale of η:

$$\eta_{min} = \eta$$

  else

    Set as a maximum vale of η:

$$\eta_{max} = \eta$$

  end if

end while

Obtain the value of η

Evaluate power coefficients:

$$\alpha_{m,l}, \quad l = \{1, \ldots, \mathcal{U}_m\}$$

given as

$$\tau = \log_2 \left(\frac{\frac{\rho \mathcal{U}_m}{K} \mid \mathbf{h}_{m,1}^H \mathbf{w}_m \mid^2}{\sigma^2} \right). \tag{5.21}$$

In Algorithm 7, we choose τ as the upper bound to find the value of η. Hence, one has to either increase or decrease the value of η and obtain the feasible solution. If the minimum value of the constraint in the optimization problem (5.20) is greater than 1, we decrease the value of η and obtain the feasible solution and vice-versa. Evidently, the stopping criterion of the bisection search is to meet an accuracy requirement of the η. Hence, we obtain power coefficients for each user in the cluster m using the proposed NOMA power allocation scheme.

5.3.3 **Complexity Analysis**

In the case of Algorithm 6, computation complexity of beam selection is $\mathcal{O}(KN)$, whereas the total time required to find η in Algorithm 7 is $L = \log_2(\frac{\tau}{\delta})$. Here, τ is the upper bound of the η and δ is the accuracy parameter of the bisection method to find the η. This implies that computational complexity of the power allocation method is $\mathcal{O}(L)$. Therefore, the upper bound of the total computational complexity is $\mathcal{O}(KN + ML)$, whereas the lower bound of the computational complexity of maximizing capacity, interference-aware, and maximum magnitude beam selection algorithms with equal power allocation is $\mathcal{O}(N^3)$, $\mathcal{O}(N^2)$, and $\mathcal{O}(KN)$, respectively. Thus, the computational complexity of the proposed algorithm is much lower than the maximizing capacity and interference-aware beam selection algorithms.

5.3.4 **Numerical Results**

The performance metric, particularly, the spectral-efficiency and energy-efficiency of the proposed "beam selection algorithm accompanied by NOMA principle followed with a power allocation scheme" is discussed in this section.

We are considering a downlink mmWave beamspace MU-MIMO communication systems having a transmitter equipped with $N = 256$ beams and $K = 16$ users equipped with a single receive antenna. The spatial channel between the transmit-

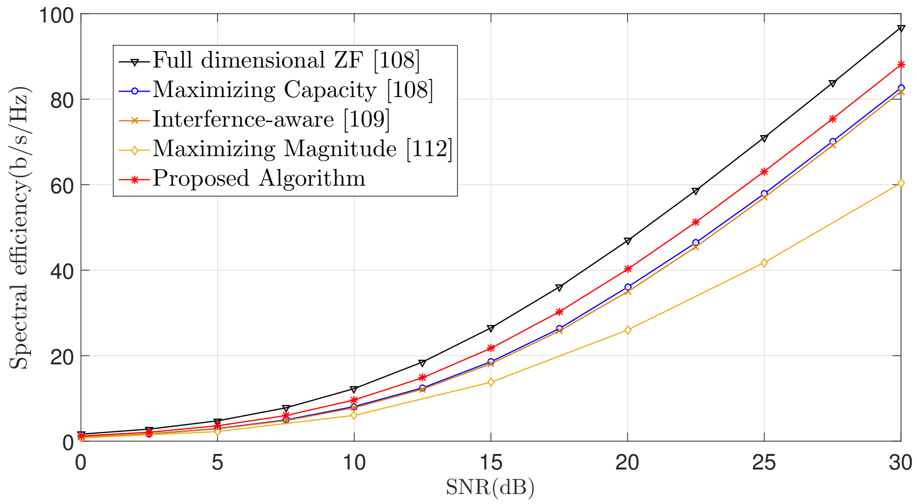

Figure 5.2 Sum-rate Performance Comparison

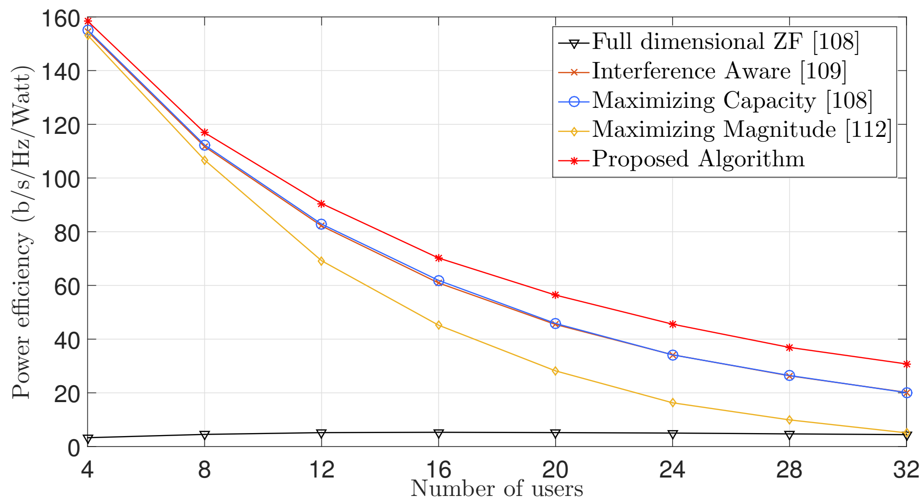

Figure 5.3 Power Efficiency Comparison

ter and user $k, k \in \{1, \ldots, K\}$, is considered to be having one LoS component with complex-valued path gain $\beta_k^{(0)} \sim \mathcal{CN}(0, 1)$ and two NLoS components with complex-valued path gain $\beta_k^{\ell} \sim \mathcal{CN}(0, 10^{-2})$, $\ell = 1, 2$. The complex-valued path gains β_k^{ℓ}, $\ell = 0, 1, 2$ are considered to be uncorrelated to each other. The spatial frequencies, θ_k^{ℓ} of user k, are uniformly distributed in the interval $\left[-\frac{1}{2}, \frac{1}{2}\right]$ and independent of each other.

Fig. 5.2 plots the achievable sum-rate of the proposed "beam selection algorithm accompanied by NOMA principle followed with a power allocation scheme." The performance of "MM" beam selection with one beam per user [113], "MC" [109], and "IA" beam selection [110] is compared. Further, it is evident that "a beam selection algorithm accompanied by NOMA principle followed with a power allocation scheme" outperforms the other existing beam selection algorithms with equal power allocation. Full dimensional ZF is the sum-rate achieved by keeping active all N beams. Note that, full dimensional ZF is one of the upper bounds on the achievable performance.

Plots in Fig. 5.3 depict the achievable power-efficiency of "a beam selection algorithm accompanied by NOMA principle followed with a power allocation scheme." The performance of the proposed algorithm is compared with the other existing beam selection algorithms. Power efficiency is defined in [53, 109, 110] as

$$\Gamma_p = \frac{R_s}{\rho + N_{RF} P_{RF}} \text{ bits/s/Hz/Watt}$$

where N_{RF} is the number of RF chains and P_{RF} is the power consumed by an RF chain. We evaluated Γ_p at SNR = 20dB, with P_{RF} = 250mW and ρ= 32mW similar to [53, 109, 110]. It is evident from the Fig. 5.3 that "a beam selection algorithm accompanied by NOMA principle followed with a power allocation scheme" achieves considerably higher power efficiency than the other existing beam selection algorithms. Note that the full dimensional ZF has very high power consumption as it keeps active all N beams.

5.4 Concluding Remarks

In this chapter, a mmWave beamspace MU-MIMO-NOMA downlink systems is discussed. In this context, the need of NOMA in the power domain for such systems is discussed. Next, a beam selection algorithm accompanied by NOMA principle at transmitter is discussed. After beam selection, a NOMA power allocation scheme is discussed to preform SIC successfully at user's end. Next, the performance metrics, i.e., spectral efficiency and energy efficiency are discussed and compared with the other existing beam selection algorithms. Further, complexities of the proposed beam selection algorithms are discussed, and compared with the existing beam selection algorithms. It has been observed that the proposed algorithms for mmWave beamspace MU-MIMO-NOMA downlink system achieves an excellent energy efficiency with less number of RF chains than the mmWave beamspace MU-MIMO downlink system.